ADVANCED MATERIALS
www.advmat.de

Organic Semiconductor–DNA Hybrid Assemblies

*Chunzhi Cui, Dong Hyuk Park, and Dong June Ahn**

Organic semiconductors are photonic and electronic materials with high luminescence, quantum efficiency, color tunability, and size-dependent optoelectronic properties. The self-assembly of organic molecules enables the establishment of a fabrication technique for organic micro- and nano-architectures with well-defined shapes, tunable sizes, and defect-free structures. DNAs, a class of biomacromolecules, have recently been used as an engineering material capable of intricate nanoscale structuring while simultaneously storing biological genetic information. Here, the up-to-date research on hybrid materials made from organic semiconductors and DNAs is presented. The trends in photonic and electronic phenomena discovered in DNA-functionalized and DNA-driven organic semiconductor hybrids, comprising small molecules and polymers, are observed. Various hybrid forms of solutions, arrayed chips, nanowires, and crystalline particles are discussed, focusing on the role of DNA in the hybrids. Furthermore, the recent technical advances achieved in the integration of DNAs in light-emitting devices, transistors, waveguides, sensors, and biological assays are presented. DNAs not only serve as a recognizing element in organic-semiconductor-based sensors, but also as an active charge-control material in high-performance optoelectronic devices.

1. Introduction

The discovery of new optical and electrical phenomena in organic materials with π-conjugated structures, commonly known as organic semiconductors, has led to the establishment of a new field of knowledge and its development for industrial applications.[1–3] The rapid increase in the number of studies on organic semiconductors and their properties facilitated the emergence of novel optoelectronic technologies through the application of chemical and material science.[4–6] Owing to their advantages, such as facile molecular tailoring for property optimization, highly flexible adaptation, and low-cost fabrication, organic semiconductors based on polymers and small molecules containing π moieties are considered as great candidates for the essential elements of next-generation miniature consumer devices.[7–9]

π-conjugated organic semiconductors have been successfully realized as a platform for various optoelectronic materials, owing to their unique light absorption, emission, and charge transfer characteristics.[10–12] Many studies have been devoted to improving the electrical and optical properties of organic semiconductors. Well-ordered assemblies based on π-conjugated polymers (CPs) and small molecules can resolve the limitations of carrier transport ability and performance stability that are common in amorphous organic materials.[13] Moreover, better-ordered organic assemblies have proved to enhance optoelectronic performance owing to their high crystallinity, thereby minimizing the grain boundaries and decreasing the defect density.[14,15] There have been reviews on the assembly of organic semiconducting materials that expound on the basic principles of molecular design and self-assembly engineering, leading to the fabrication of functional nano/microstructures derived from various types of molecules. Furthermore, relevant applications on electrical, optical, and photoelectrical devices have also been demonstrated.[16–18]

Notably, hybrid assembly has become an important aspect in the field of self-assembly.[19,20] Two or more types of organic semiconducting components are assembled into an ensemble through intermolecular interactions, such as van der Waals force, π-π stacking, and hydrogen bonding.[21,22] Hybrid assemblies can be classified into the following types: uniform-doped structures,[23–25] gradient-doped structures,[21] and hetero structures.[26–29] Most of these hybrid assemblies are utilized broadly as photonic elements, such as in light-emitting color barcodes, white light sources, optical wavelength converters, multiple optical channels, photoelectrical transducers, and chemical transducers.[19] Although these applications cover many aspects, only a few of them employ hybrid assemblies possessing biological functions.

DNAs are generally regarded as carriers of genetic information. Nevertheless, pioneering studies, such as the study on DNA nano-architectures conducted by Seeman et al., have broadened our understanding of DNA molecules.[30,31] The outstanding

Prof. C. Cui
Department of Chemistry
National Demonstration Centre for Experimental Chemistry Education
Yanbian University
Yanji 133002, China

Prof. D. H. Park
Department of Chemical Engineering
Inha University
Incheon 22212, Korea

Prof. D. J. Ahn
KU-KIST Graduate School of Converging Science and Technology and
Department of Chemical and Biological Engineering
Korea University
Seoul 02841, Korea
E-mail: ahn@korea.ac.kr

The ORCID identification number(s) for the author(s) of this article can be found under https://doi.org/10.1002/adma.202002213.

DOI: 10.1002/adma.202002213

